Fermilab

TM-1235
1100.510

Sheilding of Tevatron
Meson Laboratory
Target Piles - M-West, M-Center, M-Polarized

J. D. Cossairt
December 1983

1. Introduction

This note reports on shielding calculations pertinent to the new target piles planned for the Meson Detector Building. The primary emphasis here is upon the external dose equivalent rates and groundwater activation. A previous TM[1] describes the activation of the target, sweeping magnet cooling water, and beam sweeping magnets. A separate note summarizes the radiation protection aspects of the muon radiation due to all four Meson target piles and is attached as Appendix 1.

Figures 1 and 2 show the plans for these three target piles along with the existing ME pile. As one can see, they are quite similar in their general layout. MP is slightly more heavily shielded than MC and MW because it conveniently uses the remains of the former E613 target pile.

2. External Dose Equivalent Ratess in the Pretarget Region

In this section, the dose rates in the region upstream of the production targets is described for both the massive shields and the labyrinths.

In the pretarget region bulk shielding is driven by a desire to be adequately protected against accidental beam losses with a minimum shield thickness in order to preserve a usable crane passageway across the Detector building.

First we consider losses in the angle varying bending magnets (AVB's) upstream of the targets in the MC and MP beams. Figure 3 shows a contour plot of equal star density generated by a CASIM[2)] calculation appropriate to this situation. The top of the shield is at a radius of 12.5 ft. corresponding to a star density of 8 x 10^{-11} stars cm^{-3} per proton. Under a worst case "full machine" single pulse accident of 3 x 10^{13} protons and using the standard conversion factor of 9 x 10^{-3} mrem per star cm^{-3} one obtains 22 mrem per pulse. Thus the area above the piles could be "minimally occupied" by "authorized personnel" if interlocked radiation detectors are in place and if the area is kept locked up (Fermilab Radiation Guide Chapter 6, Table 2B), since the accidental dose equivalent is less than 50 mrem/pulse. This condition of restricted access would be inconvenient, but manageable.

It is of course important consider the possibility of scraping beam on the beam pipe preceeding the AVB's where we have approximately 3 feet of space between the beamline and the 9 feet thick concrete shield. The MP beam is the case having the longest "lever arm" in which the last string of bending magnets preceeding the AVB's is 44 feet long and begins 142 feet upstream of the production target. If we assume the presence of a limiting aperature of 3 inches (provided by a 3Q120 quadrupole, for example) 56 feet downstream of the beginning of the dipole string, we see that the maximum deviation from the central ray is 2.23 milliradians. Thus at the target box, the maximum transverse deviation would be 3.8 inches. The beam would be just contained in the planned 8 inch diameter beam pipe.

If the above analysis is incorrect and the pipe can be hit with 1000 GeV beam, TM 1140,[3] Figure 11 shows that at the surface of the concrete (correcting for the density of concrete compared to soil) we have a star density of 4×10^{-10} stars/cm^{-3} proton) yielding a dose equivalent of 108 mrem, precluding beam-on access to such an area which would have to be interlocked. It is clear, then, that limiting apertures to prevent unacceptable excursions of beams are necessary and that careful surveys (both optical and with beam losses) will be required upon initial installation.

In the horizontal plane there is, at all locations, at least 3 more feet of shielding, implying that worst case accident doses are less than 2 mrem/pulse if the beam were to hit the AVB's or less than about 10 mrem/pulse if the pipe could be hit. These are allowable provided the Detector Building floor is designated as a radiation area as it traditionally has been.

A final issue of concern in the pretarget region is that of the access labyrinths. As usual, the results of Gollon and Awschalom[4)] will be consulted. First consider the labyrinth provided to access MC. The nearest loss point to the "mouth" is 13 feet away. Making the usual assumptions that one neutron per GeV of beam energy is emitted, that the spectrum is such that we have 3×10^4 n/(cm^2 mrem), and that we have a "full machine" accident of 3×10^{13} 1000 GeV protons, at the mouth one has (at 1 TeV):

$$\frac{3 \times 10^{13} \text{ protons} \times 1000 \text{ GeV-proton}^{-1} \times 1 \text{ neutron-GeV}^{-1}}{4\pi \, (13 \times 30.48 \text{ cm})^2 \, (3 \times 10^4 \text{ n cm}^{-2} \text{ mrem}^{-1})}$$

$$= 5.07 \times 10^5 \text{ mrem}$$

The labyrinth looks at the beam decidedly "off-axis" and hence we can use the off-axis curve displayed in Figure 5 of Reference 4. The cross sectional area A of the tunnel is 22.5 ft^2 so that the "unit length" is 4.7 feet. Without taking into account any of the bends in this tunnel, the 40 feet length (8.5 units) should give an attenuation of a factor of 8×10^{-5}. Pessimistically allowing a factor of 2 for each of the seven bends combined with the "straight tunnel" attenuation results in a maximum dose equivalent 0.32 mrem per 3×10^{13} protons at the door, which is acceptable. In addition, this location is amenable to the placement of more shielding if the above attenuation factor turns out to be too optimistic.

The more normal labyrinths built to access MW and MP are opposite beam pipe. Any losses on thin beam pipes create local concentrations of radiation (as guaranteed, for example, by star density) about 20 times less than losses on beamm transport magnets. This can be seen by comparing Figures 3 and 9 of Reference 3. For these two labyrinths, the mouth is typically 3 feet away from the nearest beam pipe which will be considered to be the loss point even though it was shown above to be unlikely one. The radiation field it the source is, then, (for an accidental loss of a "normal" intensity of 5×10^{12})

$$\frac{5 \times 10^{12} \text{p- pulse}^{-1} \times 1000 \text{ GeV} \times 0.05 \text{ neutron GeV}^{-1}}{4\pi\,(3 \times 30.48\text{cm})^2\,(3 \times 10^4 \text{ ncm}^{-2} \text{ mrem}^{-1})}$$

$$= 8 \times 10^4 \text{ mrem/spill}$$

From Figure 8 of Reference 4 we can read off the attenuation factors for the three legged labyrinth:

Leg 1 (8 = 1.7 units) = 0.26
Leg 2 (9' = 1.9 units) = 0.017

Leg 3 (7.5' = 1.6 units) = 0.028

Total = 1.23×10^{-4}

So that the dose outside of the labyrinth would be 10 mrem per pulse of normal intensity. A 3×10^{13} full machine accident pulse would thus be 60 mrem; requiring the area near the ent ce to be fenced off. Interlocked detectors will be needed to limit beam losses in this area. The same detectors protecting the crane passageway will also protect the labyrinths since the same potential loss points are involved.

3. Enternal Dose Rates Near the Target Piles

These three piles are so similar that a specific Monte-Carlo Analysis of the MW pile will suffice. CASIM was used for these calculations assuming a 1 TeV proton beam incident on a 30 cm by 0.635 cm diameter beryllium target. The incident beam profile was chosen to be a Gaussian, $\sigma_x = \sigma_y = 0.1$ cm. Table 1 is a listing of the modifications to the CASIM geometry subroutine HITORM. Figure 4 shows graphical representations of the geometry cross section at various values of depth (Z) from the primary target. Note that cylindrical symmetery has been used to maximize Monte-Carlo statistics for the regions of interest for external dose rate. A secondary beam channel has been included in the beam dump to enhance the realism. The results of the calculation are shown in Figure 5 & 6 for the two cases of the extremes of magnetic field in the target pile sweeping magnets. (A field of zero for is not applicable for MP since the sweeping magnets must be on since the secondary beam channel is at zero degrees!) One can see that contours of equal star density are rearranged only slightly as a function of magnetic field. These figures also show the minimum radii of the outer boundaries of the shield at minimum. The worst star density seen is about 8×10^{-13} stars cm^{-3} $proton^{-1}$. At 5×10^{12} protons per pulse, 60 pulses per hour, this translates into 2.1 mrem/hr which is quite acceptable in such an area of minimal occupancy.

4. Soil Activation Calculations

The M-West piles contribution to groundwater activation should also be representative of the three target piles under discussion here. Again, CASIM was used to make the calculation according to the general procedure of Peter Gollon[5)]. The portion of the subroutine HITORM which defines the geometry is given in Table 2 while Figure 7 shows graphical representations of the geometry. To achieve higher statistics in the Monte-Carlo analysis, the geometry was run with mirror symmetry above and below the beam. All soil and concrete beneath the steel was presumed to be "unprotected" soil in which radionuclides produced would be potentially leachable to the groundwater. The one foot thick layer of concrete would normally not be subject to leaching. However, since the condition of the drainage under this floor is not well known it was included in the "unprotected soil" region because of the cracks due to loading which could develop in it. Its inclusion increases the groundwater concentrations of radionuclides by about a factor of two. This calculation is likely to err on the conservative side because of the large surface area protected from rainwater by the Detector Building roof.

The same beam targeting conditions as used in section 3 apply here. Table 3 gives results, with statistical errors, for star production rates in the "unprotected soil" for two different random number seeds after division by the factor of two inherent in the symmetry of the calculation. The weighted average (0.111 ± 0.015) stars/incident proton should then be representative of various targeting conditions. At an intensity of 5×10^{12} protons/spill, 60 spills per hour, 5000 hours per year we thus have 1.67×10^{17} stars per year produced in this unprotected soil.

Following Gollon in TM816,[5)] we use production rates of 0.075 atoms per star and 0.02 atoms per star for ^{3}H and ^{22}Na, respectively, which are well documented as the only radionuclides of concern in such calculations. Using the decay constants (inverse meanlife) (1.79×10^{-9} sec^{-1} for ^{3}H and 8.49×10^{-9} sec^{-1} for ^{22}Na) and the fact that 3.7×10^{10} decays per sec represent one Curie of activity one obtains, in unprotected soil:

^{3}H: 6.05×10^{-4} Ci per year

^{22}Na: 7.64×10^{-4} Ci per year

The unprotected soil with the highest specific activity is located above an elevation of about 737 feet. According to Gollon's TM816 the nearest aquifer is 60 feet below at about 677 feet and water moves downward to it at the rate of about 7.2 feet per year. All ^{3}H calculated using the above production rates is leachable while only 20% of the ^{22}Na is leachable. The ^{3}H moves downward at the water velocity while ^{22}Na moves downward at a maximum of 3.2 feet per year. Decay in transit thus yields a reduction by the following factors for the two radionuclides:

$$D_3 = (1/2)^{60/(7.2 \times 12.3)} = 0.625$$

$$D_{22} = (1/2)^{60/(3.2 \times 2.6)} = 6.75 \times 10^{-3}$$

Including these decay factors and the fractional leachability of the ^{22}Na, we obtain the following activities at the aquifer.

$$A_3 = 3.78 \times 10^{-4} \text{ Ci/year}$$

$$A_{22} = 1.03 \times 10^{-6} \text{ Ci/year}$$

After dilution in the aquifer, if one follows the very conservative (and somewhat arbitrary!) assumption commonly used at Fermilab of all of the activity migrating to a single well having a total output of 40 gallons of water per day (5.5×10^{7} cm^3 per year), one obtains concentrations of

$$C(^{3}H): 6.87\ pCi/cm^{3}$$

$$C(^{22}Na) = 0.02\ pCi/cm^{3}$$

These concentrations should be considered as upper limits due to very conservative assumptions used. The single radionuclide concentration guides for community water systems, L_i, which limit exposures from drinking water to less than 4 mrem/yr are 20 and 0.2 pCi/mℓ, for ^{3}H and ^{22}Na, respectively. Forming the sum $\Sigma C_i/L_i$ one obtains $\Sigma C_i/L_i = 0.44 < 1$. This implies that the target piles are capable of handling about 3.4×10^{18} protons per year to just reach the soil activation limit. Given the proton economy of the Tevatron era, it is highly unlikely that the three piles would ever sum to such an annual integrated intensity so that there is no problem forseen if groundwater activation from more than one of these adjacent target piles were to migrate to the same well.

Conclusion

It is thus seen that the three target piles being added to the Detector Building for Tevatron physics will have manageable external dose equivalent rates and contribute allowable groundwater activation. I would like to thank Dave Eartly for the many useful discussions we have had on this subject.

References

1. J.D. Cossairt, "Activation of Sweeping Magnets in Tevatron II 'Standardized' Target Piles", TM 1168, March, 1983.

2. A. Van Ginneken, "CASIM Program to simulate transport to hadronic cascades in Bulk Matter", FN-272, January 1975.

3. J.D. Cossairt, "A Collection of CASIM Calculations", TM 1140, October, 1982.

4. P.J. Gollon and M. Awschalom, "Design of Penetrations in Hadron Shields" in CERN 71-16, Volume 2, 1971.

5. P.J. Gollon, "Soil Activation Calculations for the Antiproton Target Area", TM 816, September, 1978.

List of Table Captions

1 Modifications to the CASIM geometry subroutine HITORM used to model the M-West target pile for external dose equivalent rate.

2. Modifications to the CASIM geometry subroutine HITORM used to Model the M-West target pile for groundwater activation.

3. Star Production in Unprotected Soil. The lower cutoff in momentum is 300 MeV/c.

TABLE 1

MODIFICATIONS TO THE CASIM GEOMETRY SUBROUTINE HITORM USED TO MODEL THE M-WEST TARGET PILE FOR EXTERNAL DOSE EQUIVALENT RATE

```
*D HITOR.27,28
      ZLIM=2000.0
      RLIM=500.00
*D MAXIM.183
      ZA=0.1
*D FIELD.3
      BX=00.00
*D HITOR.43,51
C THIS FILE IS CALLED MWESTD AND  IS A MODEL OF THE 5/83 DESIGN
C FOR THE M-WEST TARGET PILE IN THE DETECTOR BUILDING. MWESTD
C CALCULATES THE EXTERNAL DOSE RATE DUE TO THIS TARGET.
      N=0
      M=0
      AX=ABS(X)
      AY=ABS(Y)
      IF(Z.GT.30.0)GO TO 110
      N=1
      IF(RR.GT.0.1008)N=0
  110 IF(Z.GT.76.0)GO TO 120
      IF(RR.GT.524.0)N=3
      GO TO 200
  120 IF(Z.GT.107.0)GO TO 130
      GO TO 135
  130 IF(Z.GT.1387.0)GO TO 140
      M=1
      IF(AX.GT.1.43.AND.AY.GT.8.84)M=0
      IF(AX.GT.1.43.AND.AY.LT.8.84)N=3
      IF(AY.GT.10.41.AND.AX.GT.2.29)N=2
      IF(AY.GT.22.22.OR.AX.GT.9.53)N=3
      IF(AX.GT.26.04.OR.AY.GT.38.73)N=0
  135 IF(RR.GT.1938.0)N=3
      GO TO 200
  140 IF(Z.GT.1417.0)GO TO 210
      IF(RR.GT.1938.0)N=3
  200 IF(RR.GT.18813.0)N=4
      GO TO 300
  210 IF(AY.GT.15.2.OR.AX.GT.5.1)GO TO 250
      CL=-0.00625*(Z-1417.0)-3.81
      RHOLE=0.00052*(Z-1417)+0.635
      RHOLE=RHOLE*RHOLE
      OFSET=Y-CL
      RRRR=OFSET*OFSET + X*X
      IF(RRRR.GT.RHOLE)N=2
      GO TO 300
  250 N=3
      IF(RR.GT.33445.)N=4
  300 CONTINUE
```

Materials

1. beryllium
2. copper
3. iron
4. concrete ($\rho = 2.4\ g/cm^3$)

TABLE 2

MODIFICATIONS TO THE CASIM GEOMETRY SUBROUTINE HITORM USED TO MODEL THE M-WEST TARGET PILE FOR GROUNDWATER ACTIVATION

```
*D HITOR.27,28
      ZLIM=2000.0
      RLIM=500.00
*D MAXIM.183
      ZA=0.1
*D FIELD.3
      BX=18.0
*D HITOR.43,51
C THIS FILE IS CALLED MWESTC AND  IS A MODEL OF THE 5/83 DESIGN
C FOR THE M-WEST TARGET PILE IN THE DETECTOR BUILDING. MWESTB
C CALCULATES THE SOIL ACTIVATION DUE TO THIS TARGET.
      N=0
      M=0
      AX=ABS(X)
      AY=ABS(Y)
      IF(Z.GT.30.0)GO TO 110
      N=1
      IF(RR.GT.0.1008)N=0
  110 IF(Z.GT.76.0)GO TO 120
      IF(AY.GT.22.9)N=3
      IF(X.GT.15.0)N=3
      IF(X.LT.-26.0)N=3
      GO TO 200
  120 IF(Z.GT.107.0)GO TO 130
      GO TO 135
  130 IF(Z.GT.1387.0)GO TO 140
      M=1
      IF(AX.GT.1.43.AND.AY.GT.8.84)M=0
      IF(AX.GT.1.43.AND.AY.LT.8.84)N=3
      IF(AY.GT.10.41.AND.AX.GT.2.29)N=2
      IF(AY.GT.22.22.OR.AX.GT.9.53)N=3
      IF(AX.GT.26.04.OR.AY.GT.38.73)N=0
  135 IF(AY.GT.45.7)N=3
      IF(AX.GT.36.6)N=3
      GO TO 200
  140 IF(Z.GT.1417.0)GO TO 210
      IF(AY.GT.45.7)N=3
      IF(AX.GT.36.6)N=3
  200 IF(AY.GT.137.1)N=4
      IF(AX.GT.128.0)N=4
      IF(AX.GT.219.4)N=5
      GO TO 300
  210 IF(AY.GT.15.2.OR.AX.GT.5.1)GO TO 250
      CL=-0.00625*(Z-1417.0)-3.81
      RHOLE=0.00052*(Z-1417)+0.635
      RHOLE=RHOLE*RHOLE
      OFSET=Y-CL
      RRRR=OFSET*OFSET + X*X
      IF(RRRR.GT.RHOLE)N=2
      GO TO 300
  250 N=3
      IF(AX.GT.128.04.OR.AY.GT.182.88)N=4
      IF(AX.GT.219.4)N=5
  300 CONTINUE
```

Materials
1. beryllium
2. copper
3. iron
4 concrete floor
(ρ = 2.4 g/cm^3)
+ 2 ft of soil
5. soil
(ρ = 2.24 g/cm^3)
Stars in 4 and 5 are summed for soil activation calculation

Table 3

Star Production in Unprotected Soil

Seed	B(kGauss) (Sweeping Magnets)	Stars/Incident Proton
1	18	0.119 ± 0.025
2	18	0.154 ± 0.039
1	0	0.091 ± 0.027
2	0	0.095 ± 0.032
	Average	0.111 ± 0.015

List of Figure Captions

1. Plan view of Tevatron Detector Building Target Piles.

2. Cross Sections of Tevatron Detector Building Target Piles.

3. Contour plot of equal star density for AVB shielding.

4. Graphical representations of the model used to obtain external dose equivalent roles from the M-West target pile.

5. Contour plot of equal star density with a magnetic field of 18 kGauss in the sweeping magnets.

6. Contour plot of equal star density with zero magnetic field in the sweeping magnets.

7. Graphical representations of the model used to obtain soil activation estimates.

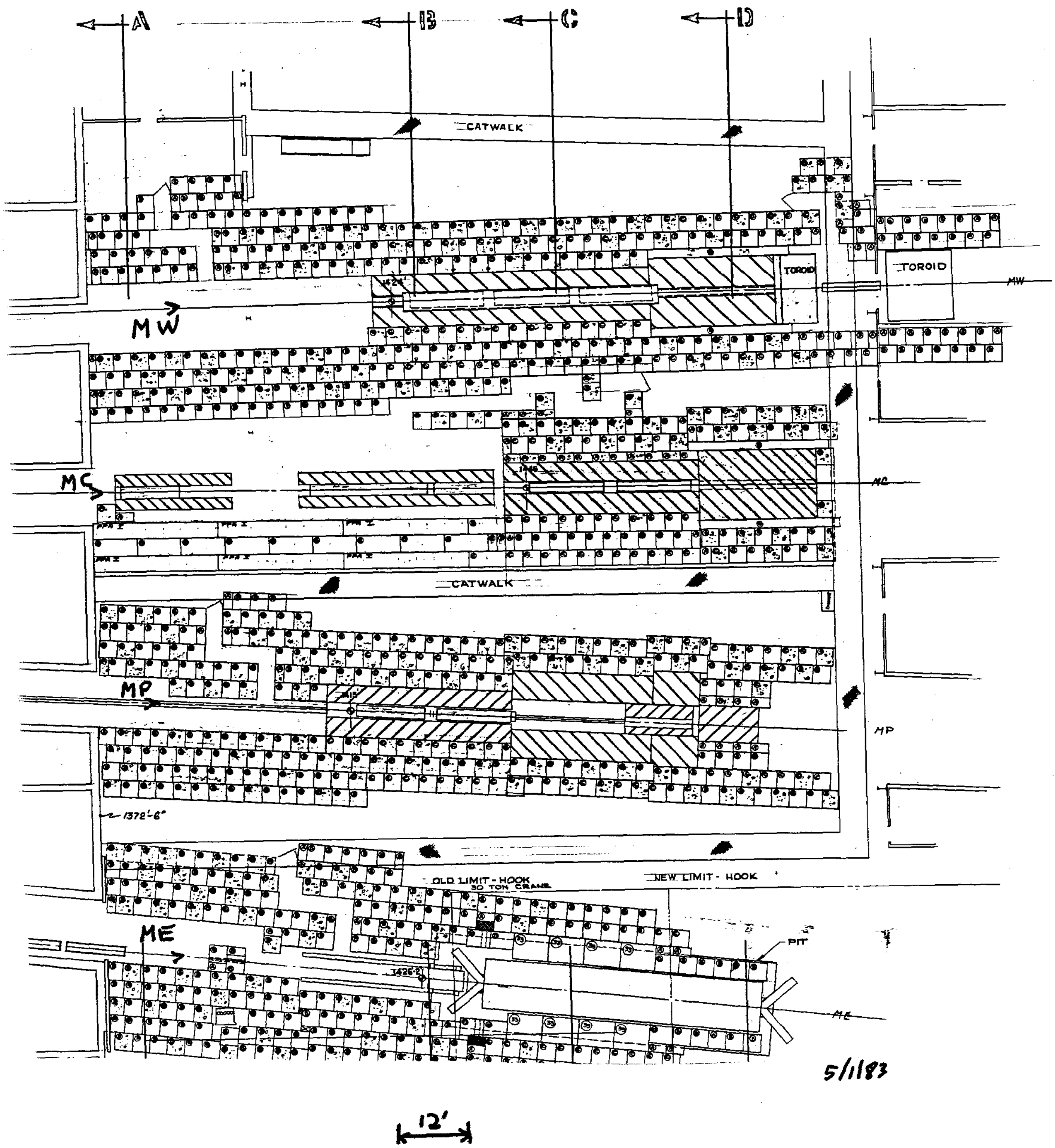


Fig. 1 Plan View of Tevatron Detector Building Target Piles Production Targets are at positions denoted ⊕

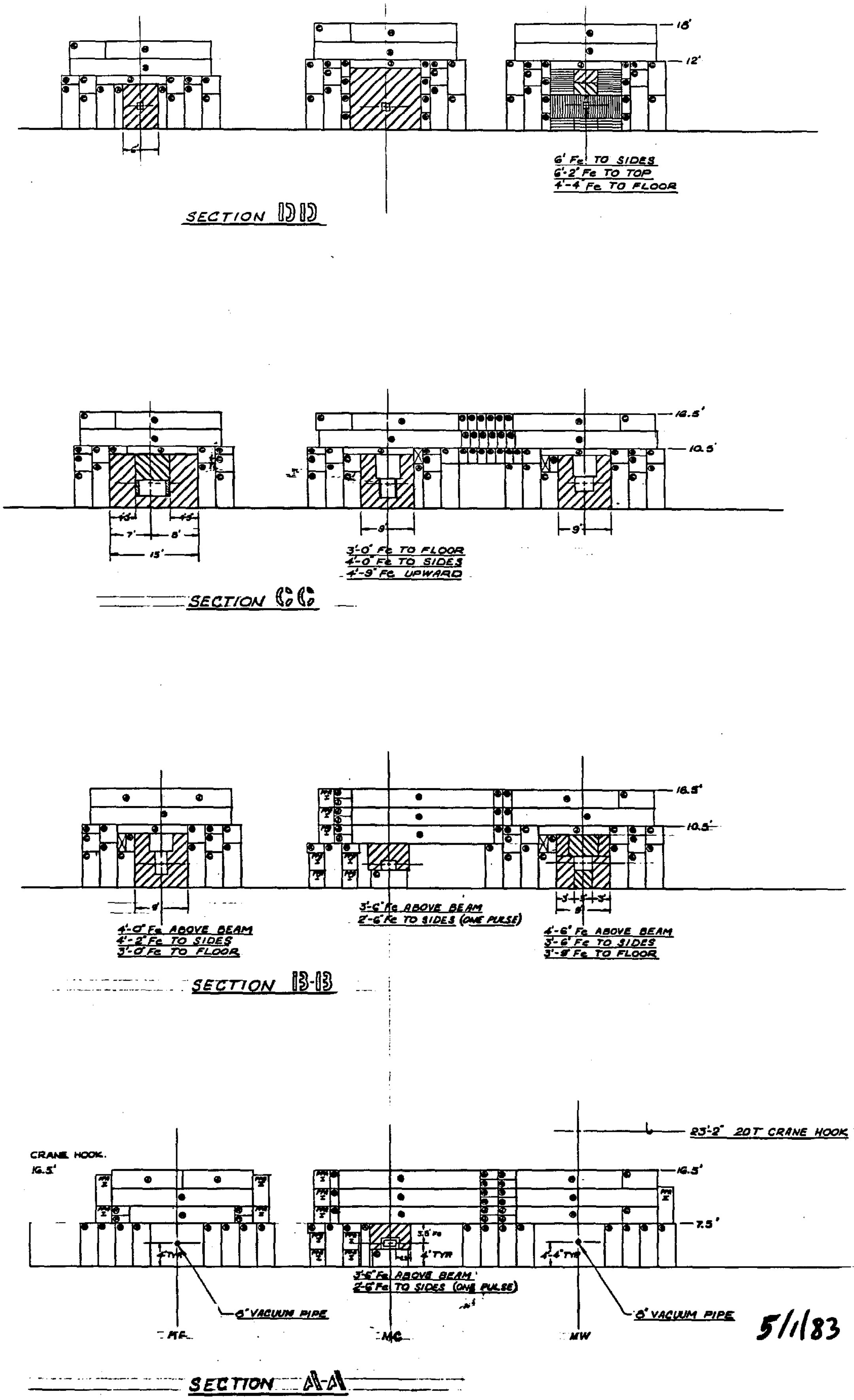


Fig. 2 Cross Sections of Tevatron Detector Building Target Piles. Cuts look upstream at lettered locations referenced to Fig. 1.

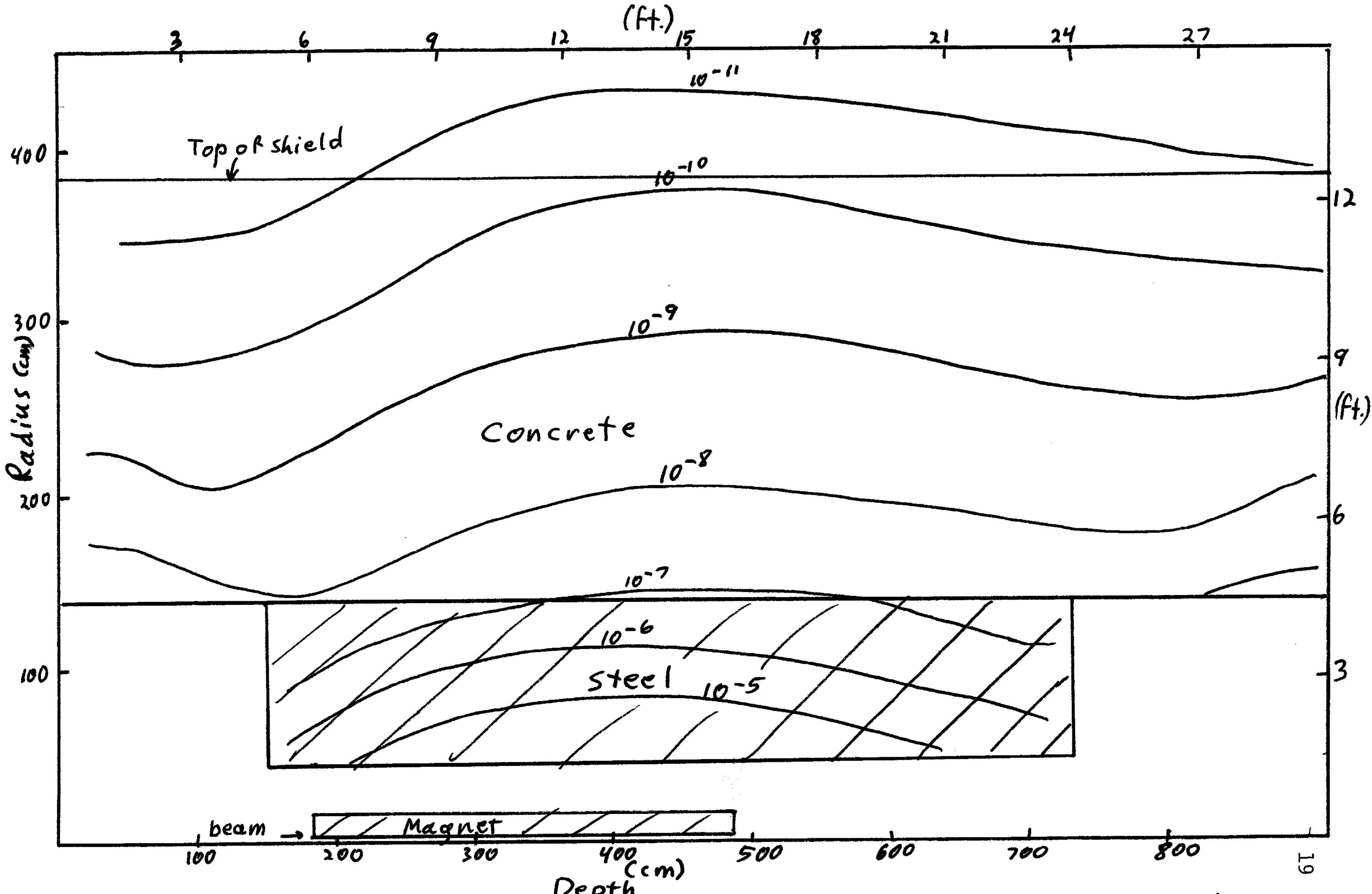
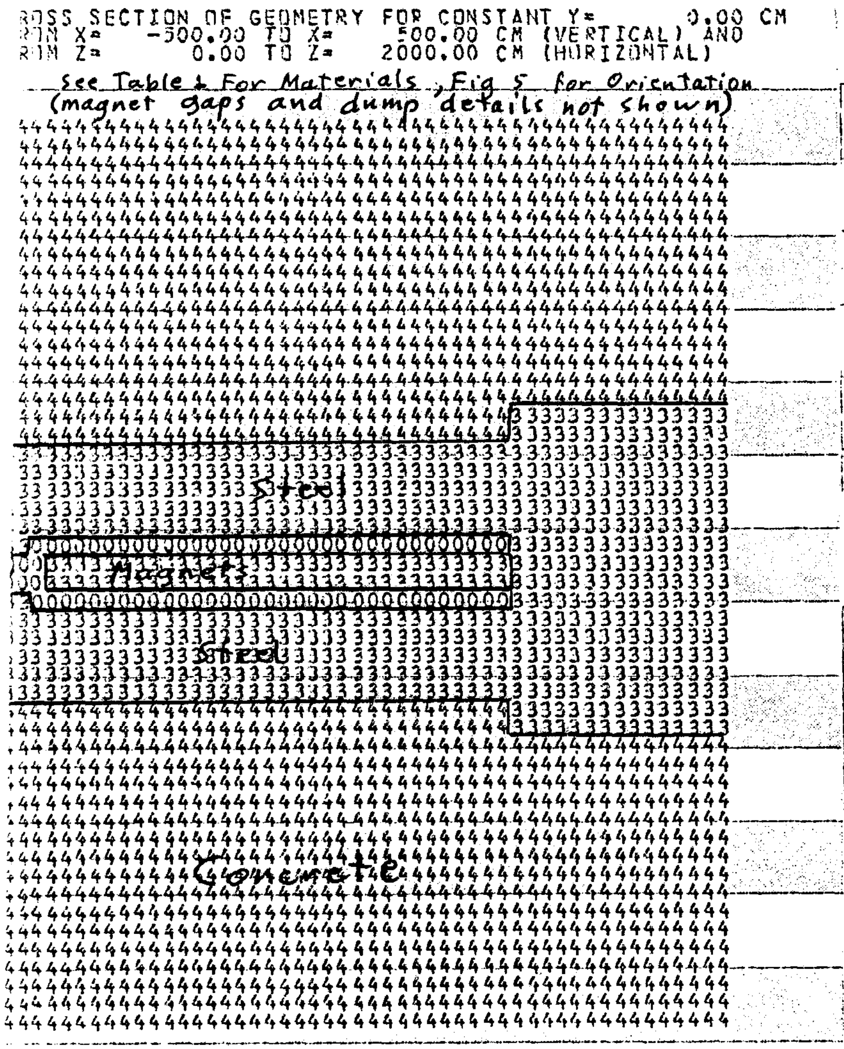
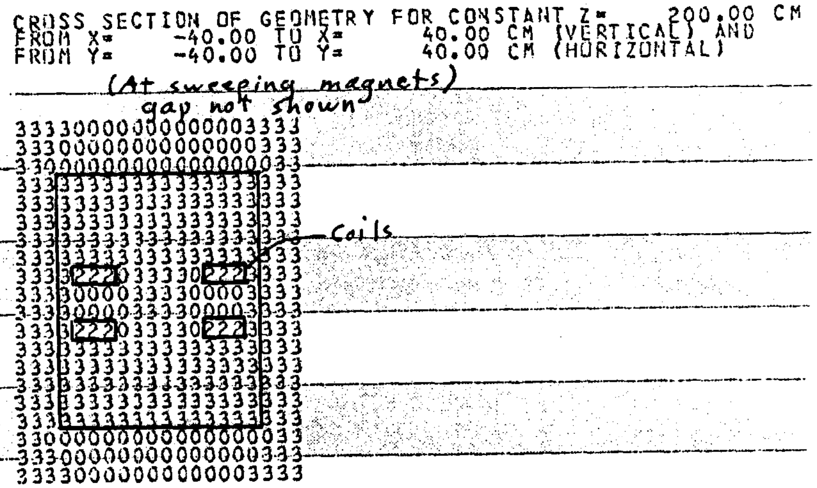


Fig. 3 Contours of equal star density (stars/cm³ per incident proton)
A beam of 1000 GeV protons ($\sigma_x = \sigma_y = 1$ mm) was incident on the face of an EPB dipole. A field of 15 kG was present in the magnet gap.





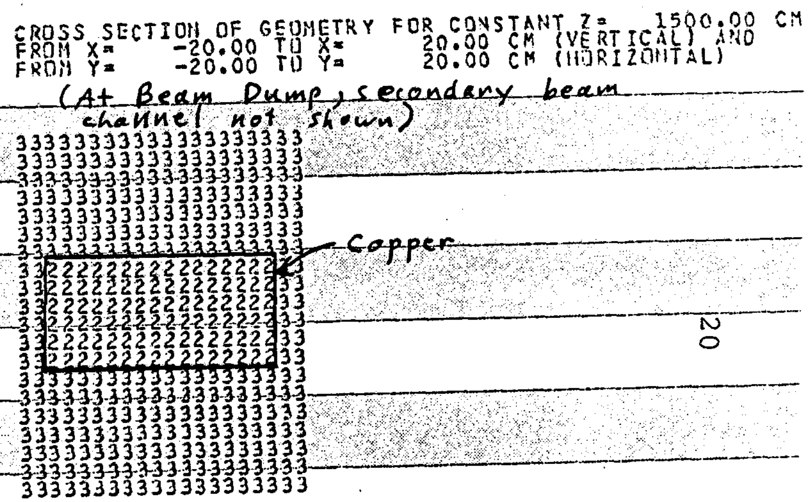


Fig.4 Graphical Representations of the model u
to obtain external dose equivalent rates f
the MWest target pile

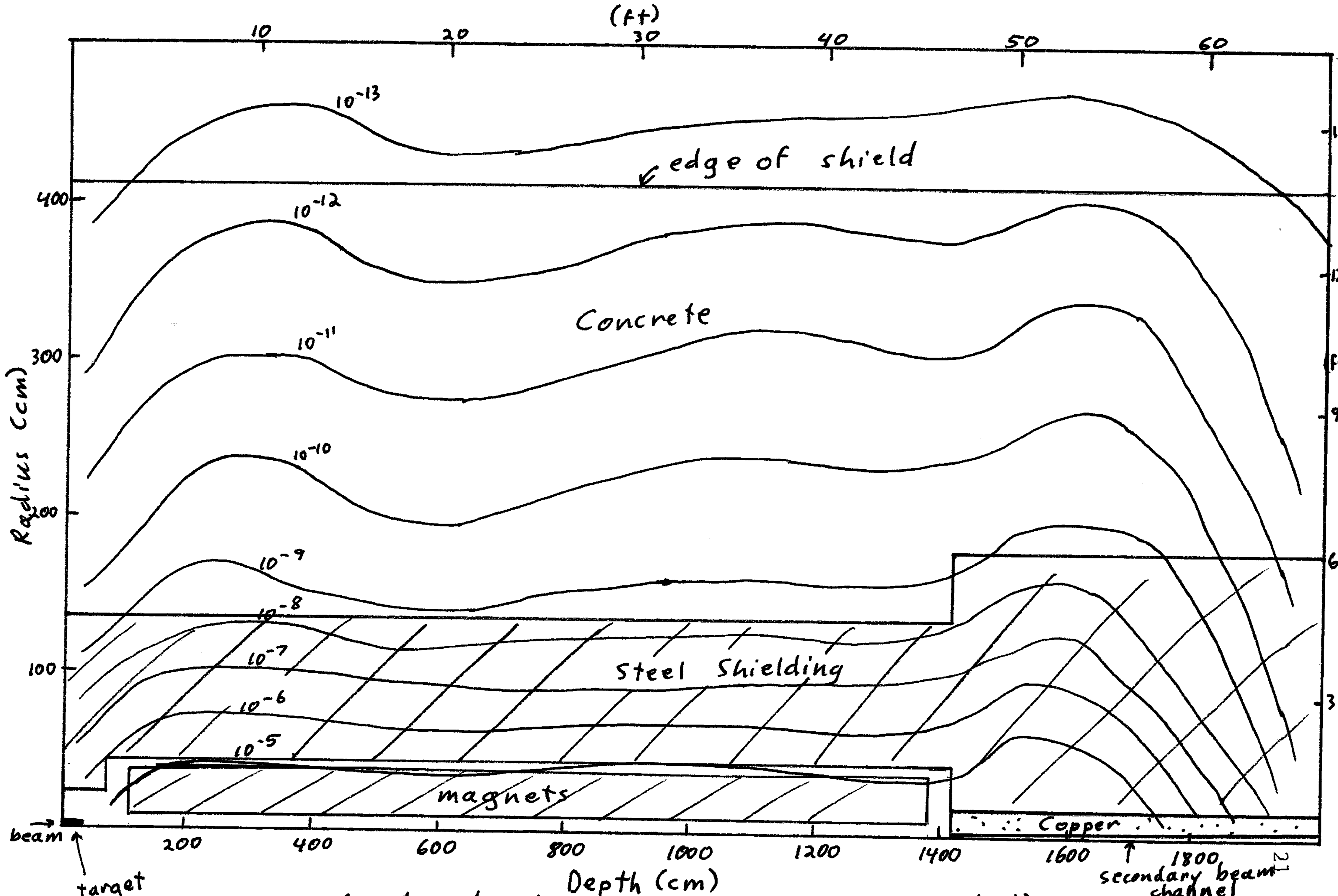


Fig. 5 Contours of star density (stars/cm³ per proton incident)
A field of 18 KG was present in the magnet gap. Shielding materials are shown in the horizontal plane.

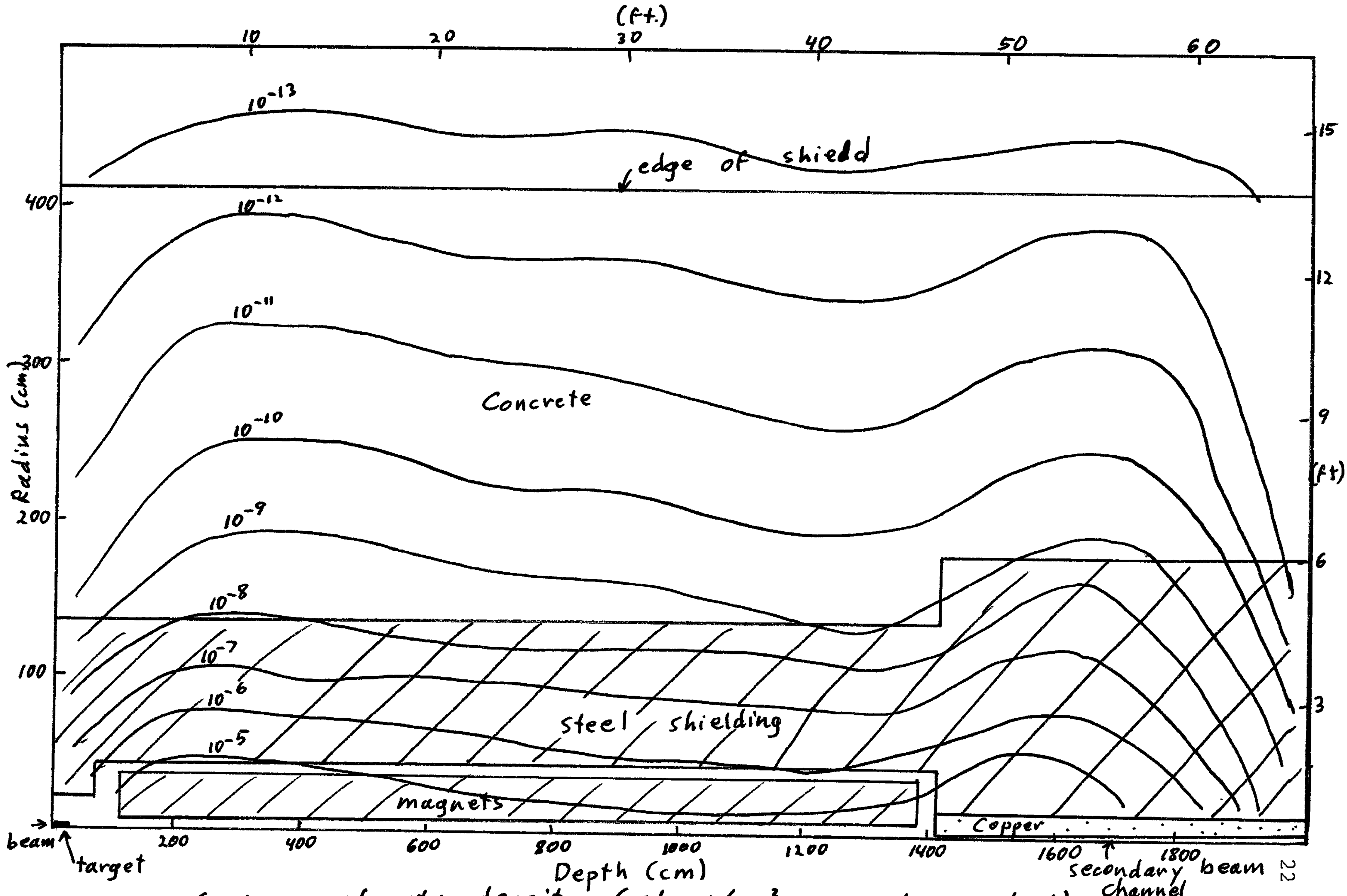


Fig. 6 Contours of star density (stars/cm³ per proton incident)
A field of zero was present in the magnet gap. Shielding materials are shown in the horizontal plane.

CROSS SECTION OF GEOMETRY FOR CONSTANT Y= 0.00 CM
FROM X= -500.00 TO X= 500.00 CM (VERTICAL) AND
FROM Z= 0.00 TO Z= 2000.00 CM (HORIZONTAL)

See Table 2 for materials
(small radius details same as in Fig 4)

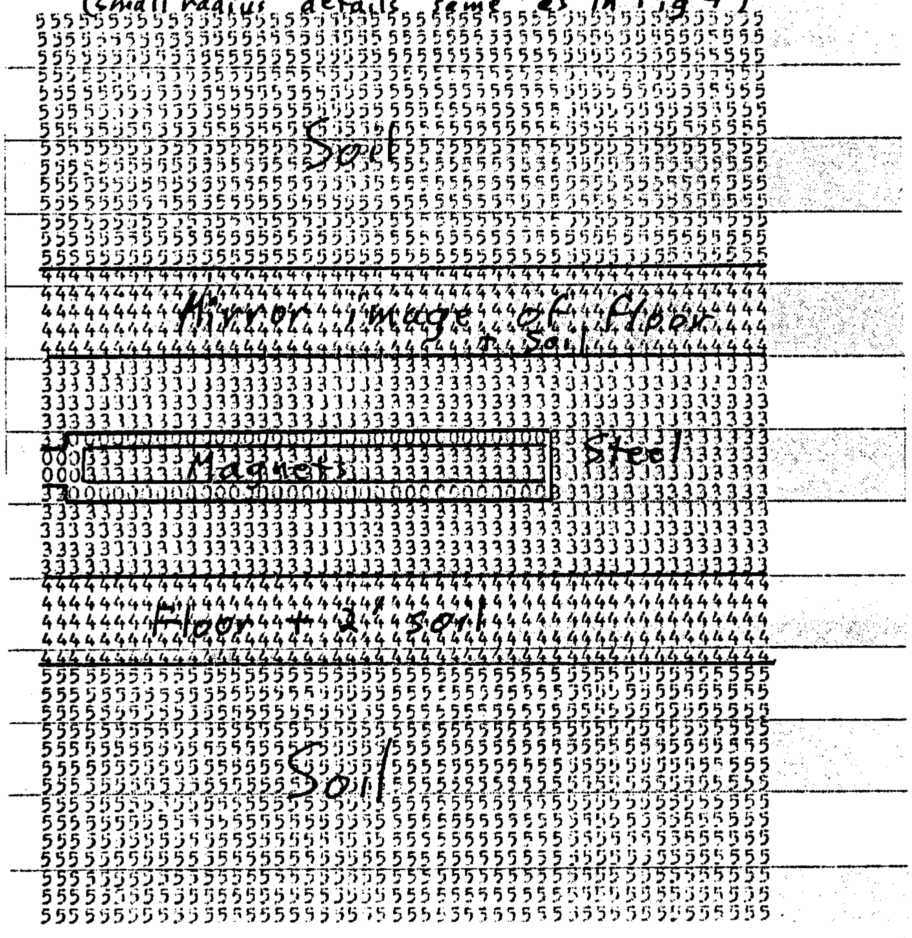


Fig. 7 Graphical representation of the model used to obtain soil activation estimates

Appendix 1

June 14, 1963

TO: KEN STANFIELD

FROM: Don Cossairt

SUBJECT: MUON DOSE RATES FROM TEVATRON MESON AREA BEAMS

This memo attempts to collect the best information I presently have concerning muon dose rates from these beams at this time. It is derived from a compilation of calculations using the program HALO done for the various beams. The calculations have been done for a variety of purposes besides radiation safety considerations so that I am simply interpreting them for this consideration. I will now describe "in a nutshell" each calculation as I understand it:

A) MW: This was done by R.Coleman to evaluate the effect of his muon spoilers upon the dose rates and detector backgrounds encountered in the experimental hall for 1000 GeV protons. He used the Malensek(FN-341) production model and investigated both π^- and π^+ decay muons for a typical targeting situation. The patterns are fairly complicated due to the nature of beam line and is decidedly NOT simple beam sweeping.

B) MC: Calculations were done by G.Bock for this beam using the Stefanski-White production model(FN-292) for 1000 GeV protons for both π^- and π^+ decays. The sweeping is essentially vertical sweeping after the production target and this shows up in the results.

C) MP: Calculations were done by me using a data file produced by A.Vasilyev of Experiments E-581/E-704. I ran the calculations using the Stefanski-White production model for 1000 GeV protons. The muon distributions are dominated by the effect of the vertical sweeping magnets which dump the proton beam so that the resulting patterns are very simple. I performed the calculation for π^-, π^+, K^-, K^+. As expected, π^- dominates since positives are dumped into the ground.

D) ME: The best calculations I could obtain were done by A.Wehmann and documented in the "Impact Statement for Proposal P-605" (March,1979) which were done for 400 GeV protons incident on a Detector Building target and for a different configuration of spectrometer magnets than was eventually constructed. I believe, however, that the field integrals are similar to those actually installed. The Wang production formula was used here. Again, this situation is largely a simple vertical sweep of the muons. Wehmann reported π^+ decays in this document as the worst case polarity of the spectrometer magnets.

I will now look at the collected results from two viewpoints; that of exposure to personnel near the beam lines, experimenntal halls, etc. and that of offsite exposure to members of the general public. In order to get worst case scenarios, I normalized everything to 5×10^{12} primary protons per spill, 60 spills per hour and did NOT do any energy scaling on the ME calculations. One year's running was assumed to be equivalent to 5000 hours at the above intensity and machine cycle(100 per cent duty factor). I assumed 28000 muons per cm^2 per mrem.

Meson backyard muon dose rates. In this area I have attempted to plot these dose rates(mrem/hr) at various elevations relative to the secondary beam height for representative values of Z. Note that since the geophysical elevation of each beam is different, the dose rates shown for each beam at, say, the nominal beam height, are not exactly coplaner. On these Figures(1-5), the arrows point toward beam line causing the adjacent dose rates. The numbers are spaced radially at 15' intervals, thus, the second number outward from a dose rate maximum is at a radius of 30 ft. At a given Z location, if values are not given, they may be presumed to be less than the smallest dose rates shown for that particular beam line. In these Figures, all decay modes included in the calculations are summed at each point. The numbers were taken on the high(conservative) side in questionable cases.

Commenting on the results, up to 10 mrem per hour is allowable in a posted radiation area of "minimal occupancy" while 0.25 mrem is the limit in porta-kamps, etc. It is likely that, for other reasons, the Meson backyard will be a posted radiation area. As one can see, the only "hot" area not well contained in an enclosure may be the west side of the MW transport enclosure near the north end of the Detector Building. The 100-300 mrem/hr seen at the lower elevations might well be inside of the enclosure(the distribution falls precipitiously with radius) or would be contained in any shielding berm installed there. The high occupied areas also seem to be assured of sufficiently low dose rates, within the accuracy of these calculations. No unsolvable problems are foreseen in these areas. It is also clear the muons are not aimed at the other experiments and do not have to be summed further downstream.

2. Site Boundary Considerations: Here we are to operate under the Fermilab Director's limit of 10 mrem/year. At the beam height, I have used a $1/r^2$ extrapolation of the maximum dose rate seen in the above Figures 1-5 at the most downstream locations shown to the site boundary defined to be at Z = 2500 meters(8200 ft) and obtain the following worst case dose rates:

MW: 16 mrem/year
MC: 4 mrem/year
MP: 3 mrem/year
ME: 0

This, of course neglects the shielding effects of "Mount Taiji". My muon measurements documented in TM-1061 indicate that the shielding hill is worth a factor of 2 to 3 in addition to $1/r^2$. This can be understood because of the fact that the hill is at least 350 ft thick everywhere at beam height(10670 cm, 21000 g/cm , or 800 radiation lengths neglecting the junk buried in it). According to Koizumi's TM-786, this ranges out muons up to 40 GeV/c. While I have no information on the muon momentum spectra, if one assumes the average in the "fringes" of these distributions, important for ground level dose rate considerations to be 50 GeV/c, multiple scattering by the hill gives about 10 milliradians of average deflection. This is comparable to the width of the distributions so that a total width of 15 millradians at points downstream of the hill would be expected in either the axis in the xy plane. Squaring, we(crudely) obtain about a factor of 2 for the effect of the hill, in rough agreement with my measurements above. This would reduce the above dose rates to less than 10 mrem/year under worst case conditions. The hill is worth keeping!

At some level, we must worry about muon beams aimed at the sky. I have taken the results of the calculation and extrapolated the maximum values seen at any height to site boundary values of Z, neglecting scattering in air. The results are listed in the following Table along with the height above the beam at the site boundary and the angle θ between the muon peak and the ground.

Beam	θ(Milliradians)	Y(ft.)	D(mrem/yr)
MW	20	168	194
MC	44	360	330
MP	23	191	420
ME	111	920	65

All of these are less than the 500 mrem/year allowed by current DOE regulations for personnel who may be identified as individuals for possible monitoring. Except for high rise building presently nonexistent, the only real exposure would be to airplane pilots who would, at most, receive only a small number of pulses per year. Construction of tall buildings would, however, eventually present a problem if they are precisely located in the worst spots.

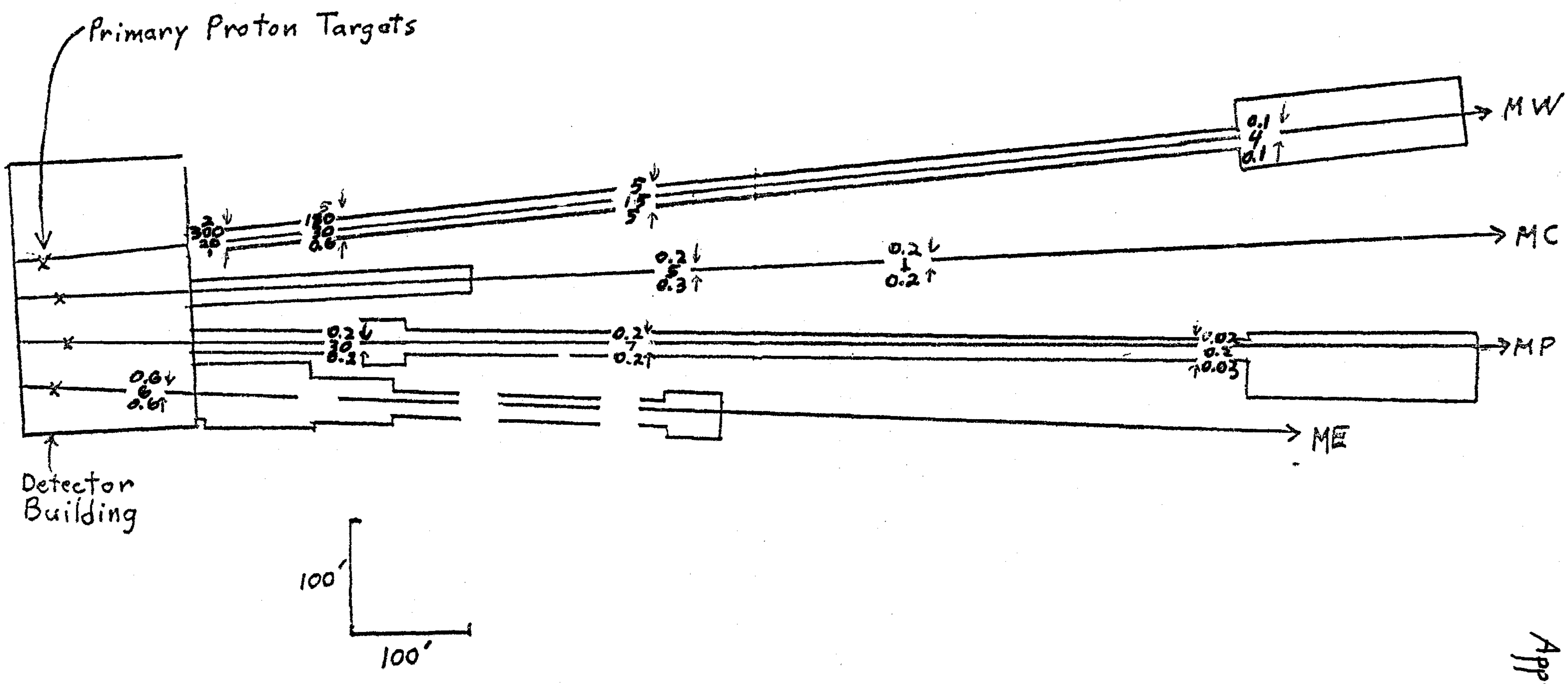
DC:cf
c: S.Butala
M.Gerardi
W.Baker
G.Bock
C.Brown
R.Coleman
A.L.Read
R.Stefanski

attachments

Predicted
Muon Dose Rates
(mrem / hr)

4' Below beams

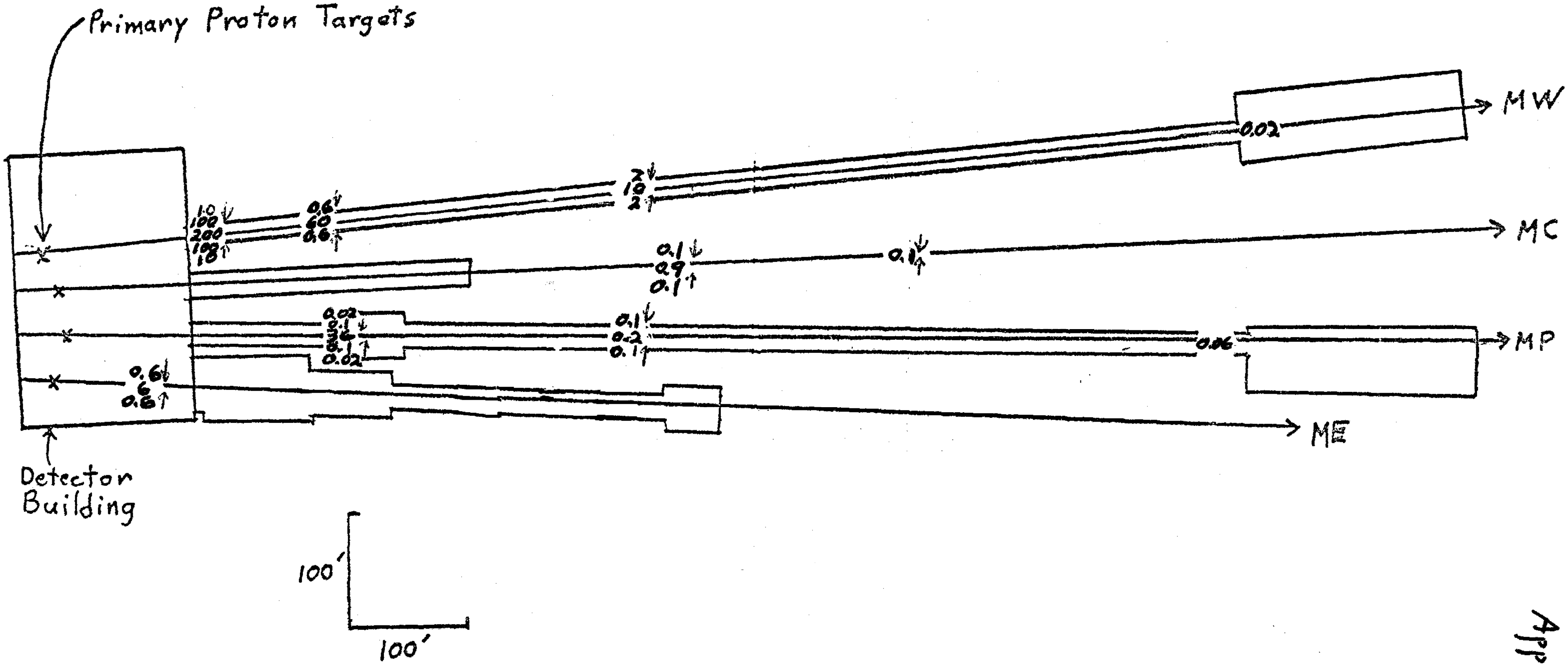
D. Cossaint
6/83



Appendix 1

Predicted
Muon Dose Rates
(mrem/hr)
At beam height

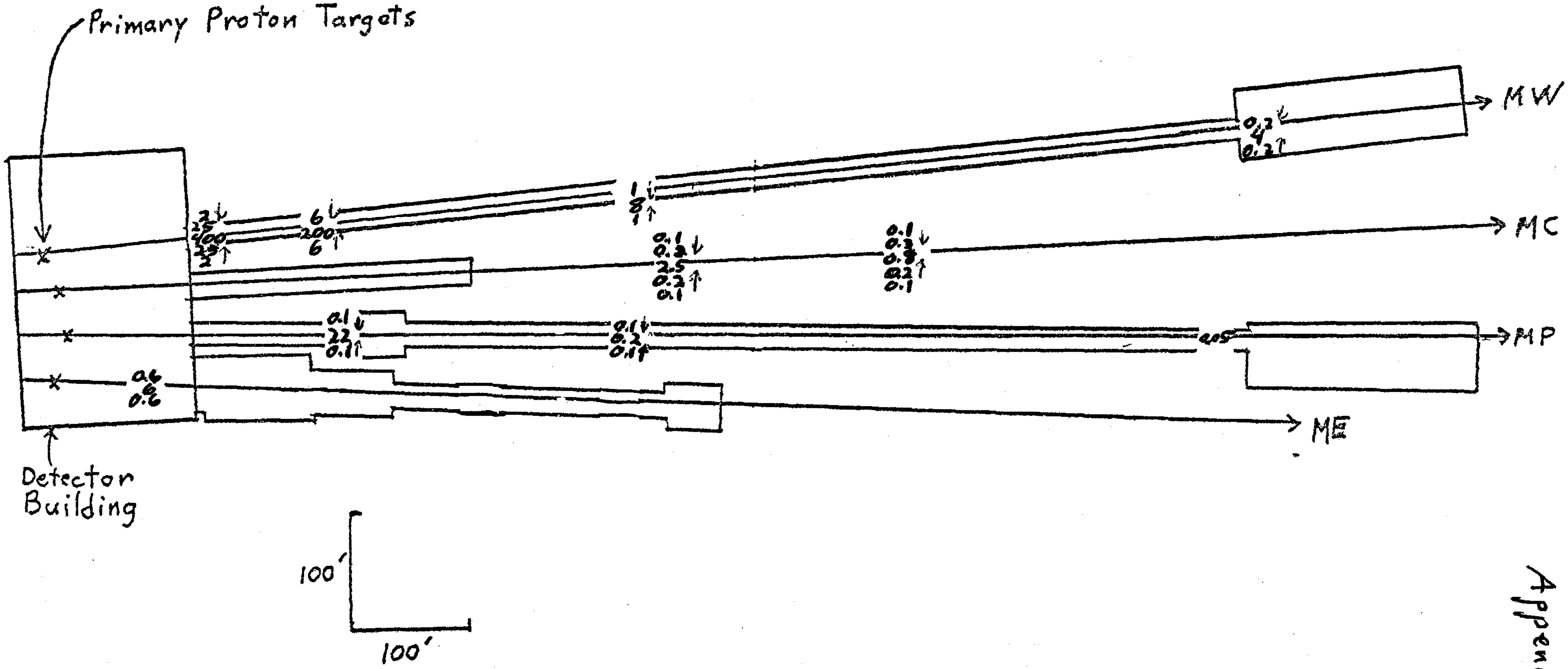
D. Cossairt
6/83



Appendix 1

Predicted
Muon Dose Rates
(mrem/hr)
4' Above Beams

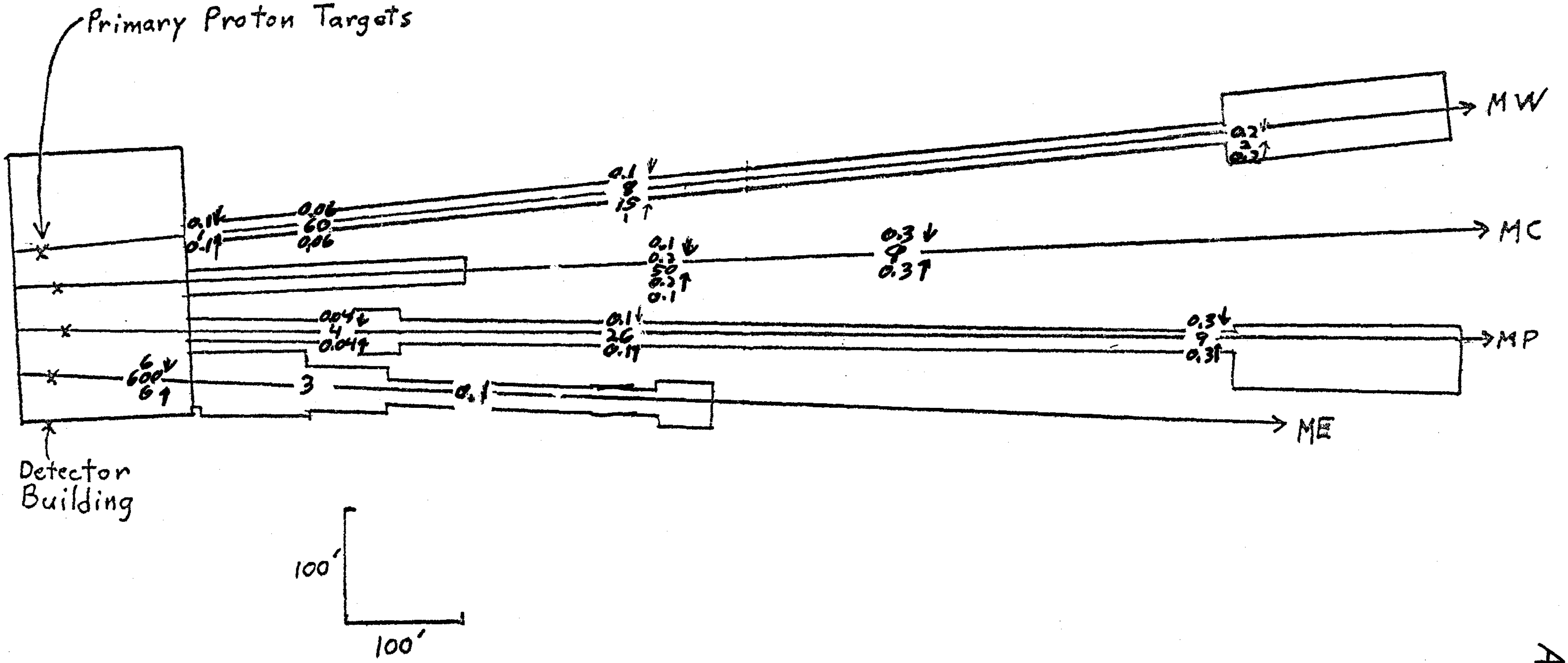
D. Cossaint
6/83



Appendix 1

Predicted
Muon Dose Rates
(mrem / hr)
10' Above Beams

D. Cossairt
6/83



Appendix 1

Predicted
Muon Dose Rates
(mrem/hr)
25' Above Beams

D. Cossaint
6/83